Title of Investigation:

Optical Measurements of Particulate Organic Carbon in the Sea

Principal Investigator:

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Other In-house Members of Team:

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Other External Collaborators:

Viktor Feygels (EG&G)

Initiation Year:

FY 2003

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

\$65,500

FY 2004 Authorized Funding :

\$37,500

Actual or Expected Expenditure of FY 2004 Funding:

In-house: \$6.250; Contracts: \$31,250

Status of Investigation at End of FY 2004:

Completed in FY 2004

Expected Completion Date:

December 2004

Purpose of Investigation:

Natural and human-induced climate change has, and will continue to have, profound effects on biospheric carbon cycling. Observing and predicting such changes are important components of NASA's objective to "understand and protect our home planet." In the oceans, three primary carbon pools are present: Dissolved Organic Matter (DOM), Dissolved Inorganic Carbon (DIC), and Particulate Organic Carbon (POC). By far, the largest of these is DIC, and it is through this pool that ocean carbon dioxide exchanges with the overlying atmosphere. However, the rate and extent of this exchange is strongly influenced by biological processes occurring within the POC pool.

While never demonstrated, an opportunity clearly exists for studying and monitoring ocean carbon pools from space if a technique can be developed that measures ocean light scattering from above the atmosphere. The overarching objective of this study, therefore, was to develop such a system for assessing the concentration of carbon particles in the ocean. The basic approach we adopted for this project was to use a lidar system (a laser light source combined with a receiving telescope) that measures light scattering over a range of different fields of view (FOV), which will be varied by a computer-controlled, mechanical iris within the light path of the lidar's telescope. The underlying principle is that, as the telescope FOV increases from very narrow to very wide, the light collected changes from being dominated by photons scattered only once by an in-water particle to photons experiencing multiple scattering events in the water before returning to the telescope. This permits calculations of the beam attenuation in the water, which is directly proportional to the number of particles.

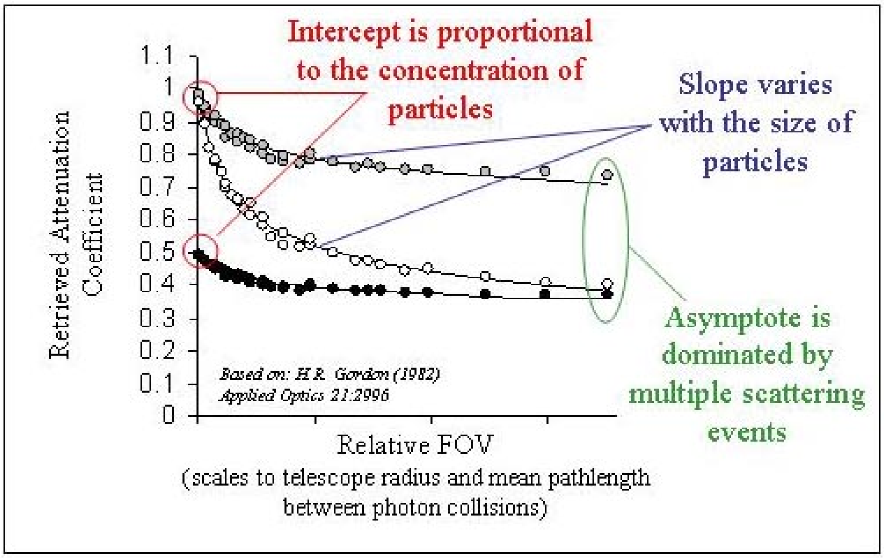

Figure 1. Theoretical basis of our lidar system development. In this figure, light attenuation is measured for three different particle populations. The solid black symbols represent a region with low concentrations of particles that are relatively small. The gray symbols represent a population with approximately twice as many particles as the solid black symbols, but of the same size. The open symbols would correspond to a population of larger particles, but of the same concentration as the gray symbols.

Accomplishments to Date:

Dr. Viktor Feygels, who conducted additional theoretical analyses of the fundamental optical principles originally outlined in 1982, began our efforts (Figure 1). Based on these studies, a final design for the lidar's telescope was completed and construction began. The central components were first assembled and tested on an optical bench at the NASA Wallops Flight Facility (Figure 2).

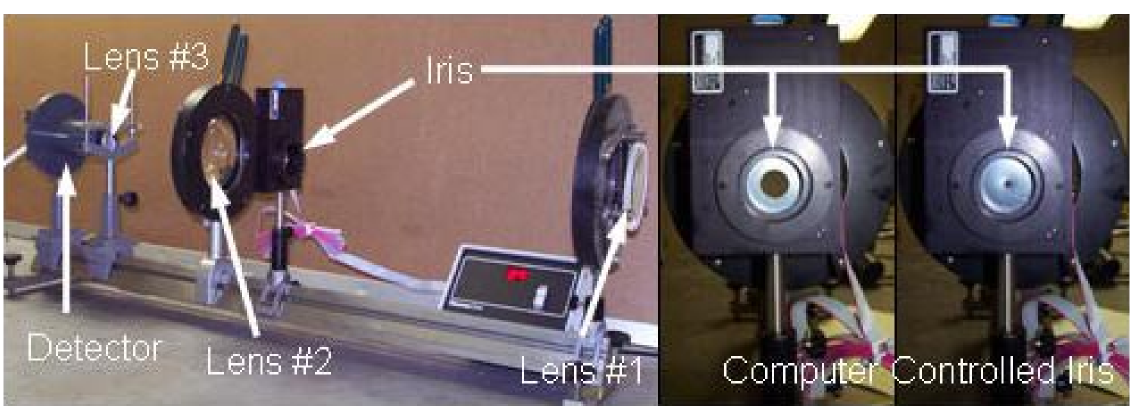

Figure 2. Initial setup and testing of the telescope components for the particulate carbon lidar showing the three central lenses, specialized photomultiplier (PMT) detector, and the computer controlled iris for achieving measurements of scattering at variable FOVs.

Following these initial tests, the telescope casement was machined, the laser light source (532 nm) was acquired and integrated into the system, and computer hardware and software purchased and developed. The fully assembled lidar was then successfully tested in the air using two targets at different distances and at different angles (Figure 3).

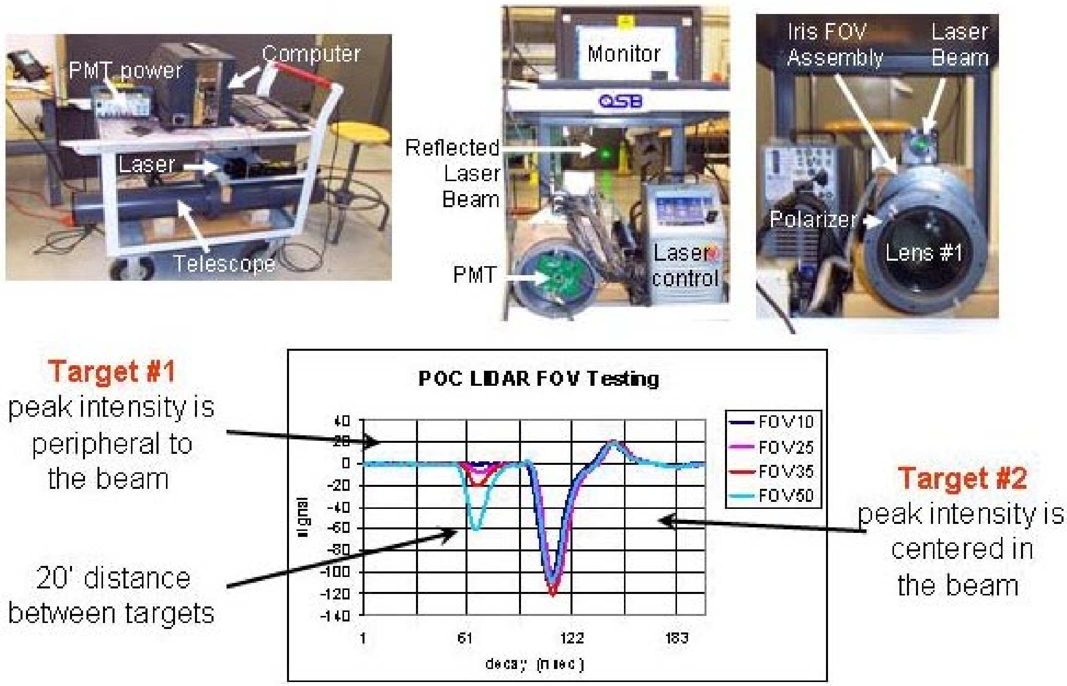

Figure 3: Initial setup and testing of the telescope components for the particulate carbon lidar

Finally, the lidar system was tested in the water using the wave tank facility at NASA Wallops Flight Facility (Figure 4) to better simulate retrievals at multiple FOV in the medium of interest (i.e., seawater). For this test, the lidar was positioned outside the tank and the laser light reflected off a primary mirror within the wave tank and then down the length of the tank where targets at different distances were placed. The return signal was then captured and target distances solved analytically.

Figure 4: Testing in the seawater wave tank

While no patents or publications have resulted from this study, the basic approach of retrieving information on ocean particle concentrations from measures of light scattering has developed into a new remote-sensing mission concept, called the Physiology Lidar Multispectral (PhyLM) mission. The PhyLM concept was initially the merger of a high-resolution ocean radiometer with a lidar system that incorporated multiple fields-of-view, precisely as investigated under this Director's Discretionary Fund (DDF) project. As the concept matured, the FOV number was reduced to only two, as new calculations indicated that additional FOVs were unnecessary. A detailed design study has since been conducted on the PhyLM concept. A proposal for a Goddard-led PhyLM mission is awaiting the upcoming Earth System Science Pathfinder (ESSP) Announcement of Opportunity.

Planned Future Work:

Our current plan for evolving the concepts is through the development and competition of the PhyLM mission, a central focus of which is the accurate space-based retrieval of global ocean particulate organic carbon concentrations.

Summary:

The project's innovative features included optical retrievals of underwater waveforms at multiple telescope FOVs. Because of this work, the Goddard Space Flight Center has validation data for an approach that could evolve into a future remote-sensing mission. Optically retrieving estimates of scattering layers that agree with measured in-water objects was the criterion for success. Using retrieved optical data to determine scattering characteristics related to particulate carbon concentrations was one of the technical risk factors.

The instrumentation developed during this project, the measurements conducted, and the parallel research conducted during the project regarding the retrieval of particle scattering data from space indicate that:

(1) The multiple FOV approach investigated is a viable technique for assessing particle concentration in the laboratory and field.

(2) Complications associated with simulating the multiple FOV approach from space will likely complicate its application from space.

(3) A very viable option for assessing particle abundance from space is to determine backscattering coefficients instead of beam attenuation, which was the goal of the current project.

(4) Backscattering coefficients can be determined using a nadir-looking, single FOV lidar or through inversion-based analyses of passive remote-sensing ocean color data.

(5) Initial studies on using ocean color data to quantify ocean particles have provided strong evidence that the approach is feasible.